Study of Gold Wire Bonding on 0.1 μm Soft Gold Film Substrate

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***Abstract*—0.1 μm soft gold film substrate was ultrasonic bonded with 0.6 mil gold wire, which effectively reduced gold assumption comparing to the traditional 0.3~0.5 μm soft gold film substrate. The substrate showed good bondability by wire pull test (WPT) and perfect reliability by high temperature storage test (HTST). The bonding structure in failure mode of wire pull test was studied by focused ion beam (FIB) and scanning electron microscope (SEM) observation. A design of experiments (DOE) was set up to figure out the optimistic process window for gold wire bonding on Ni-Pd-Au substrate.**

Keywords—wire bonding; 0.1 μm soft gold; process window; bondability; reliability;

I. Introduction

Ultrasonic wire bonding has been the most extensively used method to interconnect IC chips and substrates, due to the cost advantage and mature technology [1]. Nowadays, as the attention of packaging industry begins to shift from merely ensuring reliable manufacturing process to optimizing process for efficiency and productivity further cost reductions are being sought [2]. There are two ways to eliminate the high-cost gold, not just from the wire, but also from the substrate.

On the wire side, wire diameter reduction is an effective way to reduce cost. However, smaller gold wire diameter may cause smaller sweep stiffness of the wire bond and higher risk of wire sweep [3]. In that case, copper and other alloy wires have been studied to replace conventional gold wire. Copper, with superior electrical and thermal conductivities as well as higher elongation and hardness, requires higher ultrasonic power and bonding force, probably leading to high risk of physical damage like cratering for ball bonding [4]. As for the alloy wire, an innovative Ag-8Au-3Pd alloy wire has been developed recently. With the same crystal structure of gold, silver and palladium, the Ag-8Au-3Pd alloy wire has turned out to be an economical substitute for gold wire interconnects. However, the technology is not mature enough, which remains further study [5].

On the substrate side, the electronics packaging industry still works with electrolytic nickel / palladium / (soft) gold (Ni/Pd/Au) to provide both a highly solderable and wire bondable surface for wire bond applications. Nickel and palladium layer are able to absorb bonding energy and prevent metal diffusion, which makes nickel and palladium layer the supporting layer and barrier layer [6]. The soft gold (SG) film on the substrate fingers is about 0.3~0.5 μm to achieve high reliability wire bond. To cut down gold assumption, thin-gold-film substrate and other alternative material is studied. The stitch bonding (2nd bond) quality cannot be guaranteed, which might show faulty soldering and non-stick on lead (NSOL) [7]. So thin-gold-film substrate has great limitation on reliability.

In this paper, the soft gold film thickness on finger was decreased to 0.1 μm to cut down gold assumption. A design of experiment (DOE) was set up to investigate the bondability of 0.1 μm soft gold Ni/Pd/Au substrate bonded with 0.6 mil gold wire. The bonding surface morphology and bonding interface of the 0.1 μm SG film substrate (Ni/Pd/Au) and 0.3 μm SG film substrate (Ni-Au) were observed by scanning electron microscope (SEM) and focused ion beam (FIB). Wire pull test (WPT) and high temperature storage test (HTST) were carried out to confirm the reliability. The different failure modes were also studied.

II. Experimental

A. 0.1 μm SG film substrate bondability study

The bonding was performed between 0.6 mil (15.2 μm) gold wire and 0.1 μm gold film substrate. Plasma activation of gold films was carried out before bonding, using an argon (Ar) radio frequency for 6 minutes. To avoid oxidation and sulfuration, the bonding was under the protection of 95% nitrogen and 5% hydrogen atmosphere. The bonding temperature was 175 ^{o}C. The ball bond (1st bond) was on Al pad of 1 μm thickness and the stitch bond (2nd bond) was on Ni/Pd/Au substrate with 0.1 μm soft gold film, as shown in Fig. 1. Wire pull test (WPT) and mean time between alarms (MTBA) were used to evaluate the bonding parameters. As for the WPT, the hook position was closed to stitch bond, which we called stitch pull test. The stitch pull test can be used to test the bonding strength of 2nd bond. A three factors (USG current, Force and contact velocity (C/V)) and two responses (WPT and MTBA) DOE was set to determine the process window.

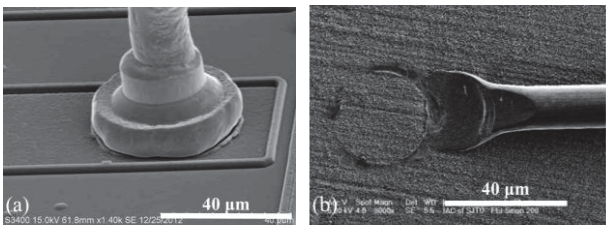

Fig. 1. SEM images of 1st bond and 2nd bond: (a) 1st bond, (b) 2nd bond

B. 0.1 μm SG film substrate reliability study

High Temperature Storage Test (HTST) was performed in oven at 175 °C in an air environment. HTST is usually conducted to simulate the reliability of the bonding interface over time [8]. During different time intervals, 0 hours, 100 hours, 250 hours and 500 hours, WPT was subjected to study the microscopic morphology optical microscope. The bonding strength and storage function up to the standard of JEDEC were good.

C. Microscopic observation of wire pull test failure mode

The failure mode after WPT was shown as Fig. 2. The fish tail was found during bonding interface of the sample with fail tail bond. The fish tail would undoubtedly weaken bonding strength. The samples after WPT were subjected to the focused ion beam (FIB) test for failure mode study, and observed by scanning electron microscope (SEM) with back scattered electron (BSE) imaging, FEI Nova Nano-SEM 230.

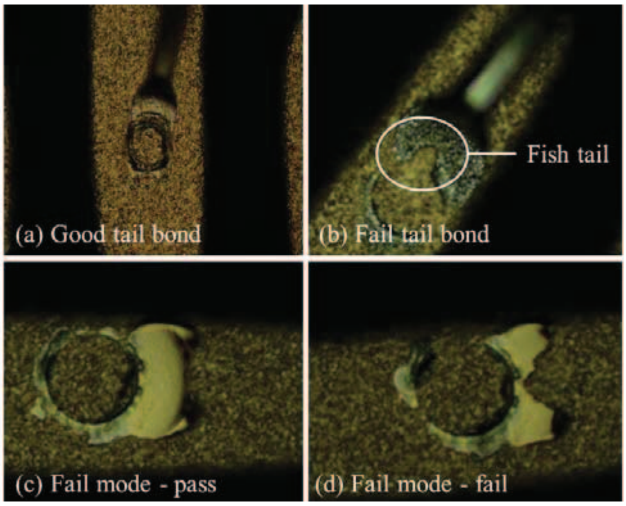

Fig. 2. SEM images of failure mode after WPT

III. RESULTS AND DISCUSSION

A. Bondability study

To figure out the optimum bonding parameters and the process window for the gold wire and 0.1 μm SG film substrate bonding, raw response data after the wire bond was studied. The mean and performance index of process (Ppk) of the stitch pull test data were proportional to USG current, Force and C/V respectively, analyzed by JMP, as shown in Fig. 3. In this situation, we set C/V as 0.6 mil/ms, and simulated by contour profiler to find the optimum parameters, as shown in Fig. 4. So the force was set from 50~65 gf, USG from 142~160 kHz.

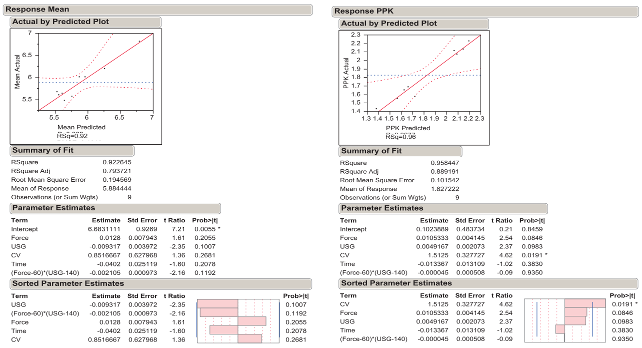

Fig. 3. JMP analysis about the crucial factors to WPT during wire bonding

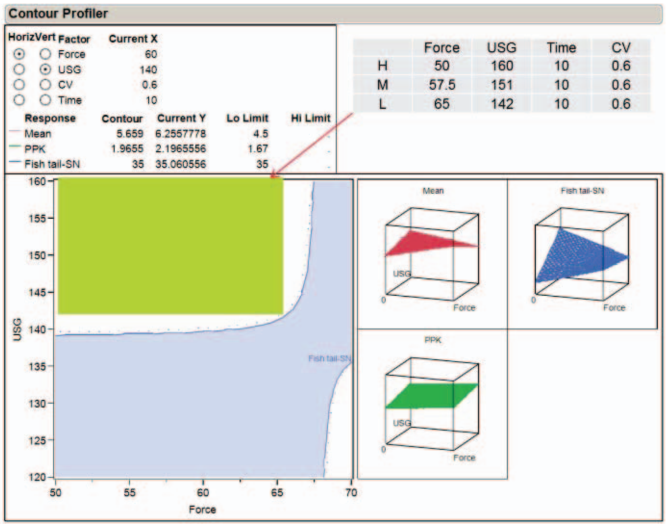

Fig. 4. The simulative curve of USG, Force and WPT data

B. Reliability study

Bonds on 0.1 μm SG film substrate were baked at 175 °C up to 500 hours in an air atmosphere. The HTST test result indicates bonds on 0.1 μm SG film substrate were reliable, as shown in Table 1. The WPT specification is that minimum wire pull strength should be over 1.5 gf for 0.6 mil wire and Ppk should be over 1.67. As shown in Table 1, the WPT data met most of the specification, except that Ppk was a little lower than 1.67. However, we can still come to the conclusion that the wire pull mode pass after HTST. The wire pull fracture structure of samples before HTST and after 500 hrs HTST were observed by optical microscope, as shown in Fig. 5. The remained gold wire was almost the same in size and morphology, comparing to the original samples without HTST. High reliability was guaranteed by the same performance of samples before and after HTST. Since the connection between wire and film on substrate was a gold-to-gold connection, there was no intermetallic compound (IMC) formation. That also helps prove the good reliability on another side.

TABLE I. WIRE PULL STRENGTH DATA DURING HTST

Leg	HTST	Wire pull test (/gf)					Wire pull mode (fail/pass)
		Max	*Min*	*Avg*	*STDEV*	*Ppk*	
1	0 hrs	3.34	2.20	2.79	0.31	1.38	Pass
2	100 hrs	4.10	2.61	3.21	0.39	1.48	Pass
3	250 hrs	3.11	2.08	2.52	0.27	1.26	Pass
4	500 hrs	3.19	2.03	2.69	0.30	1.33	Pass

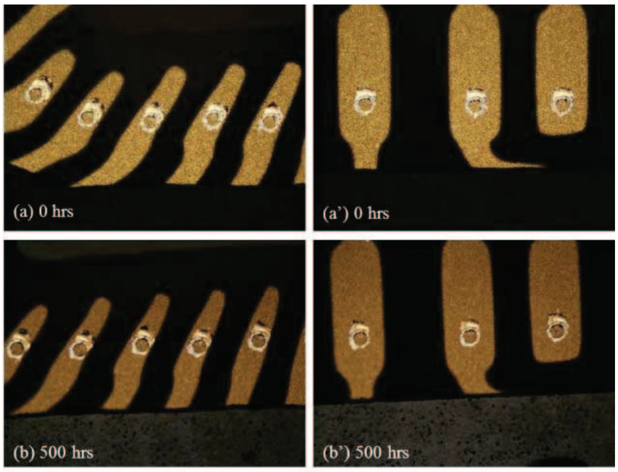

Fig. 5. Wire pull fracture structure: (a) Without HTS, (b) After 500 h HTS

C. *Fail mode bonding interface study of 0.1 μm SG film substrate*

The sample which cannot meet the specification of WPT was carried out to do the FIB test. There is diffusion happened between Ni and Au, while the counts of Ni to Au was nearly 40 to 750, as shown in Fig. 6. The Au and Pd layer were so thin that the hardness of substrate was mainly determined by Ni layer. However, during wire bonding, the Au and Pd layer can play the role as a buffer zone to improve bondability. So thin SG film substrate might disqualify wire bonding. Bonding interface of sample failed in WPT was compared to that of 0.3 μm film substrate, using the same 0.6 mil Gold wire for bonding, as shown in Fig. 7. In the image, we can clearly see the Ni/Pd/Au layer, also the gold layer from the wire side. Comparing the images of point 1 and point 4, also those of point 2 and point 5, which were nearly the same place of the bonding, gaps can be found. The gaps were in gold-to-gold bonding interface. So we could come to the conclusion that the weakest bonding place happened on gold. The Au from wire and substrate sides cannot form good combination. It was because of the different hardness of gold wire and substrate. 0.1 μm thickness under some bonding process was not enough to work as buffer zone to ensure the bonding. Gaps can be eliminated by adjustment of USG and other bonding process.

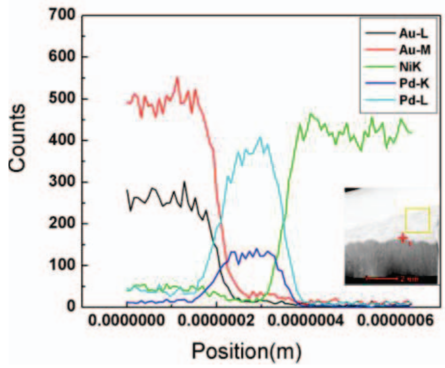

Fig. 6. Bongding interface images of 0.1 μm SG film substrate by TEM

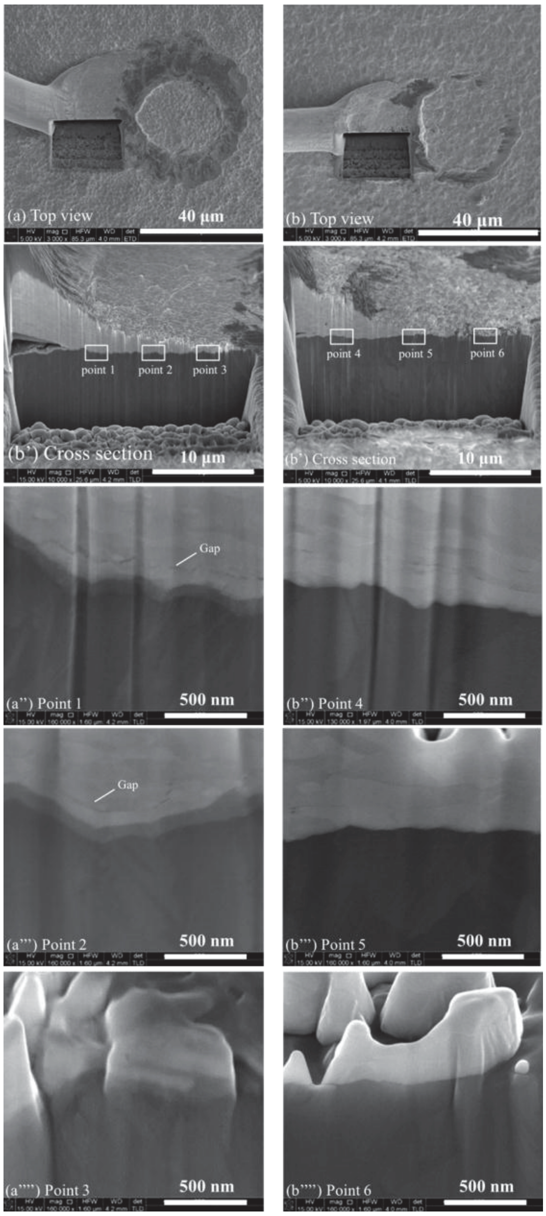

Fig. 7. Bongding interface images by FIB: (a) 0.1 μm SG film substrate, (b) 0.3 μm SG film substrate

IV. CONCLUSION

In this study, 0.6 mil gold wire bonding on 0.1 μm soft gold film substrate was successfully developed instead of that on 0.3 μm soft gold film substrate.

- A DOE was set up to investigate the process window of 0.1 μm soft gold film substrate bonding. The research showed that the 0.6 mil Gold wire bonding on 0.1 μm SG had good performance on bondability test.
- The bonding interface of failed sample was studied by FIB and TEM. Gaps between golden wire layer and golden finger layer showed that the breakage happened between gold layers. Adjusting the USG and bonding process can eliminate the gaps.
- HTST and pull fracture observation showed that no deterioration even after 500 hrs baking, which indicates a perfect reliability of the bonding method. These studies have demonstrated a feasible and high reliability substrate for gold wire bonding.

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